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SKY-BRIGHTNESS AND DAYLIGHT-ILLUMINATION MEASUREMENTS.*

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SYNOPSIS.

The brightness of the sky was measured almost daily at the American University, Washington, D. C., between April 5 and July 14, inclusive, and at Chicago, Ill., between July 19 and August 13, inclusive, 1921.

The illumination from sunlight and skylight combined, and from skylight alone, was measured on a horizontal surface, and also on a surface normal to the incident solar rays; and at Washington, in addition, measurements were made of the skylight illumination on vertical surfaces facing 0°, 45°, 90°, 135°, and 180° in azimuth from the sun.

The measurements were made with a Sharp-Millar photometer, the constants of which have been checked frequently at the United States Bureau of Standards.

About half the Chicago measurements were made on top of the dome of the Federal Building, in the Loop district, one of the smokiest sections of the city. The remainder were made at the University of Chicago, which in summer is comparatively free from smoke when the wind blows from the lake. Southeast and southwest winds, however, bring considerable smoke from South Chicago and the Union Stockyards, respectively.

There is little smoke in the atmosphere at the American University, D. C.

A comparison of the Washington and Chicago measurements shows that toward the sun on cloudless days the sky brightness does not differ materially at the two places, but opposite the sun the horizon in Chicago is darkened by the smoke, especially in the Loop district.

With a cloudless sky the direct solar illumination at Chicago is noticeably weaker than at Washington, and in the Loop district, with the sun not more than 40° above the horizon, it averages only 80 per cent as intense. The illumination on a vertical surface facing 180° in azimuth from the sun, computed from the sky-brightness measurements, averages only about two-thirds as intense as the illumination computed from similar measurements for Washington.

PHOTOMETRIC UNITS.

In photometric measurements, as in all others, a unit of measure is required. In the United States the International candle is the unit generally employed.

For the purpose of this paper three definitions become necessary, as follows:

(1) *Luminous flux*, = F. = radiant power evaluated according to visibility, i. e., capacity to produce the sensation of light. The flux emitted in a unit solid angle by a point source of one candle power = one lumen.

(2) *The illumination on a surface*, = flux density on the surface, = F/S, where S is the area of the surface. Thus, a flux of one lumen has a surface density of a foot-candle at a distance of one foot, a meter-candle at a distance of one meter, and a phot at a distance of one centimeter. There are 30.48 centimeters in one foot; therefore one phot = 929 foot-candles, since $(30.48)^2 = 929$.

(3) *The brightness* of a perfectly-diffusing surface radiating or reflecting one lumen per square centimeter is one lambert. It is equivalent to a perfectly-diffusing surface with an illumination of one phot.

OBSERVATIONAL PROGRAM.

Sky brightness.—The source of the brightness of the sky is threefold: (1) The direct diffusion of sunlight by the gas molecules and dust and other particles in the atmosphere; (2) reflection of light from the surface of the ground and other objects; (3) secondary diffusion of light by the atmosphere. The diameters of gas molecules are small as compared with the wave length of light and cause a greater proportion of scattering at the blue end of the spectrum than at the red end, giving the sky its blue color. The diameters of the dust and other particles in the atmosphere are generally large as compared with the wave length of light. These particles therefore reflect the white light from the sun, and greatly dilute the blue color of the sky.

When detached clouds are present they reflect a variable percentage of the light that they receive, depending upon both the angle of incidence and the angle of reflection of the light. If the cloud layer is continuous, and everywhere of equal thickness and density, it approaches a matt surface, and its underside should be everywhere of equal brightness.

From the laws of diffusion or scattering and of the reflection of light, it follows that the brightness of the sky should be symmetrical on the two sides of a vertical circle through the observer and the sun, unless the cloud or haze distribution is unsymmetrical, or the surface of the earth under the two sides differs materially, as for instance, land under one side and water under the other. In order to economize the time required for making the measurements, it has been assumed that the sky brightness is symmetrical on the two sides of the sun's vertical. Measurements are therefore confined to one side, and it is generally a matter of chance on which side they are made.

The observational program calls for a series of measurements as nearly as possible when the altitude of the sun above the horizon is 0°, 20°, 40°, 60°, and 70°. Not many observations are obtained in summer with solar altitudes 0° and 20°, and none can be obtained in winter with solar altitudes 60° and 70°. A complete series of readings includes measurements at 2°, 15°, 30°, 45°, 60°, 75°, and 90° above the horizon on vertical quadrants of circles at 0°, 45°, 90°, 135° and 180° of azimuth from the sun's vertical. Three photometric settings are made at each point, or 105 settings for each series, which latter generally requires from 10 to 12 minutes of time.

For the purpose of classifying the observations they have been grouped according to the solar altitude at the time of the measurements and the state of the sky. Skies have been classified as follows: (1) clear, when few or no clouds are present in the half of the sky measured; (2) overcast with thin clouds or dense haze; (3) completely covered with clouds or dense fog, so that neither the sun nor blue sky can be seen; (4) covered with clouds from which rain or snow is falling; and (5) partly overcast with clouds. This latter includes all that can not be included in the first four classifications.

Illumination.—At Washington, with a clear sky, the total daylight illumination (solar + sky) is measured on a

*Condensed from the *Report of the Committee on Sky Brightness*, Illuminating Engineering Society, as presented at the Annual Convention, Rochester, N. Y., Sept. 26 to 29, 1921, by Herbert H. Kimball, Chairman of the committee. Published in *Transactions of Illuminating Engineering Society*, Oct. 10, 1921.

horizontal surface and on a surface normal to the incident solar rays, and the skylight illumination on the same surfaces and also on vertical surfaces facing 0°, 45°, 90°, 135°, and 180°, in azimuth from the sun. With a cloudy sky the skylight illumination is measured on a horizontal surface, and on vertical surfaces oriented as above, the sun's azimuth being calculated approximately.

At Chicago, measurements were made of the total daylight illumination, and of the skylight illumination alone, on a horizontal surface, and also on a surface normal to the incident solar rays, when no clouds were present. With a cloudy sky the skylight illumination was measured on a horizontal surface only.

A compensated test plate was employed in all illumination measurements. The certificate furnished by the Electrical Testing Laboratories, New York, shows that the deviation of the measured brightness of the plate from the theoretical brightness, according to Lambert's cosine law, is less than 1 per cent for all angles of incidence up to and including 40°, and is only −2 per cent at 80°.

Figure 1 shows the photometer mounted in its shelter on the roof of the College of History, American University, D. C. The sides of the shelter rise to the level of the center of the test plate when the elbow tube of the photometer is horizontal. The inside of the shelter is painted flat black, and measurements indicate that its coefficient of reflection is only about 3 per cent. This greatly reduces the reflection of light to the test plate from objects below it.

Resting on the photometer is a shade that is used to shield the test plate from direct sunlight when desired.

SUMMARY OF SKY BRIGHTNESS MEASUREMENTS.

A summary of these measurements can best be shown by graphic methods, as in figures 2 and 3. Half the sky on one side of the sun's vertical is shown in stereographic projection in Figure 2 (*a*) to (*h*), inclusive, and Figure 3, (*a*), (*b*), (*c*), and (*e*). Figure 3, (*d*) and (*f*), are for the half of the sky farthest from the sun. The figures at one end of the lines of equal sky brightness give the brightness relative to the zenith. At the other end, they give the brightness in millilamberts.

The data for Washington represent the means of measurements obtained on about 25 clear half days, 29 cloudy half days, and 15 half days with the sky covered with thin clouds or haze. Those for Chicago represent about seven clear half days and only one cloudy day.

Figure 2, (*a*), (*b*), and (*e*), for Washington, show the change that occurs in the brightness of a clear sky with increase in solar altitude. In general, there is a point of minimum brightness a little less than 90° from the sun and in his vertical, and a dark valley extends from this point to a point between the sun and the horizon. The brightest area is about the sun, and the brightness generally increases from the zenith towards the horizon. These charts are in good accord with those constructed by Dorno [1] from measurements made at Davos, Switzerland, except that the horizon, and the sky opposite the sun, is in general brighter at Davos than at Washington, especially in winter, probably because of the greater amount of light reflected to the sky by the snow-covered Alps. Some unpublished measurements made by F. W. Little at Key West and Sand Keys, Fla., and off Long Island, N. Y., give a darker horizon opposite the sun than is given by the Washington data, probably because most of Little's measurements were made over a water surface, which is a poor reflector of light. Dorno [2] found the albedo of a snow surface to be from 60 per cent to 74 per cent, the latter for newly fallen snow, as compared with 6 to 7 per cent for grass-covered ground, and 2 per cent for a water surface. He also found that with the sun 30° above the horizon its surface brightness is 1,000,000 times the brightness of the clear sky in the zenith.[3]

A comparison of figure 2, (c) and (d), for Chicago with figure 2, (b), for Washington shows marked similarity, except that at Chicago the horizon opposite the sun is darker than at Washington. This is especially the case in the "Loop" district, where, at azimuth 135° from the sun, the measurements show the horizon to be less than half as bright as at Washington.

The data of figure 2, (f), for Washington and (g) and (h) for Chicago, with a cloudy sky, show a radical departure from the data for cloudless skies. The brightest area is near the zenith, from which there is a nearly uniform decrease in brightness in all directions to the horizon. In the "Loop" district of Chicago the horizon is again less than half as bright as the horizon at Washington.

This darkening of the horizon can not be attributed to the influence of Lake Michigan, since with a clear sky it is quite as marked in the morning, when the photometer tube is pointed away from the lake, as in the afternoon, when the tube is pointed toward the lake. It must be attributed to the smoke cloud, which is dark in color in comparison with either the clear sky or cloud surfaces.

Mention should here be made of a series of measurements of the brightness of the sky in the zenith made at Chicago between October, 1897, and August, 1899,[4] which gives for the annual mean zenithal brightness at noon, expressed in candles per square foot, for a cloudy sky 200 candles; a clear sky, 305 candles; and a sky covered with thin clouds, 620 candles. Expressed in millilamberts, these become 676, 1031, and 2096, respectively. The two latter values approximate the brightness of the sky at Washington under like conditions with respect to clouds, when the sun is 40° above the horizon. The value for a cloudy sky is about that for a sky in Washington covered with clouds from which rain is falling with the sun 20° above the horizon.

The monthly mean values with a clear sky are higher than measurements at Washington with the sun at corresponding altitudes above the horizon, while the monthly means for a cloudy sky are markedly lower, especially during the fall and winter months.

The data of figure 3, (a), shows that at Washington thin clouds or dense haze increase the brightness of the sky, especially in the zenith and near the sun. This is the brightest type of sky measured at Washington.

With rain falling the brightness distribution is much the same as with a cloud or fog-covered sky, but the absolute brightness averages only about half as great.

With the sky partly covered with clouds the brightness varies from that of a clear sky to that with a sky covered with thin clouds or dense haze. Luckiesh[5] and Aldrich,[6] working independently, have found that dense

[1] Dorno, C. Himmelshelligkeit, Himmelspolarisation und Sonnenintensität in Davos 1911 bis 1918. *Veröffentlichungen des Preusischen Meteorologischen Instituts.* Nr. 303. Abhandlungen Bd. VI.

[2] Loc. cit., p. 214.

[3] Loc. cit., Table 14.

[4] Basquin, O. H. Daylight Illumination. II. Brightness of the Sky. *The Illuminating Engineer*, New York, Dec., 1906. Vol. 1, pp. 823–829.

[5] Luckiesh, M. The Visibility of Air Planes. *Jr. Franklin Institute*, 1919, vol. 187, p. 306.

[6] Aldrich, L. B. The Reflecting Power of Clouds. *Smithsonian Misc. Coll.*, vol. 69, No. 10.

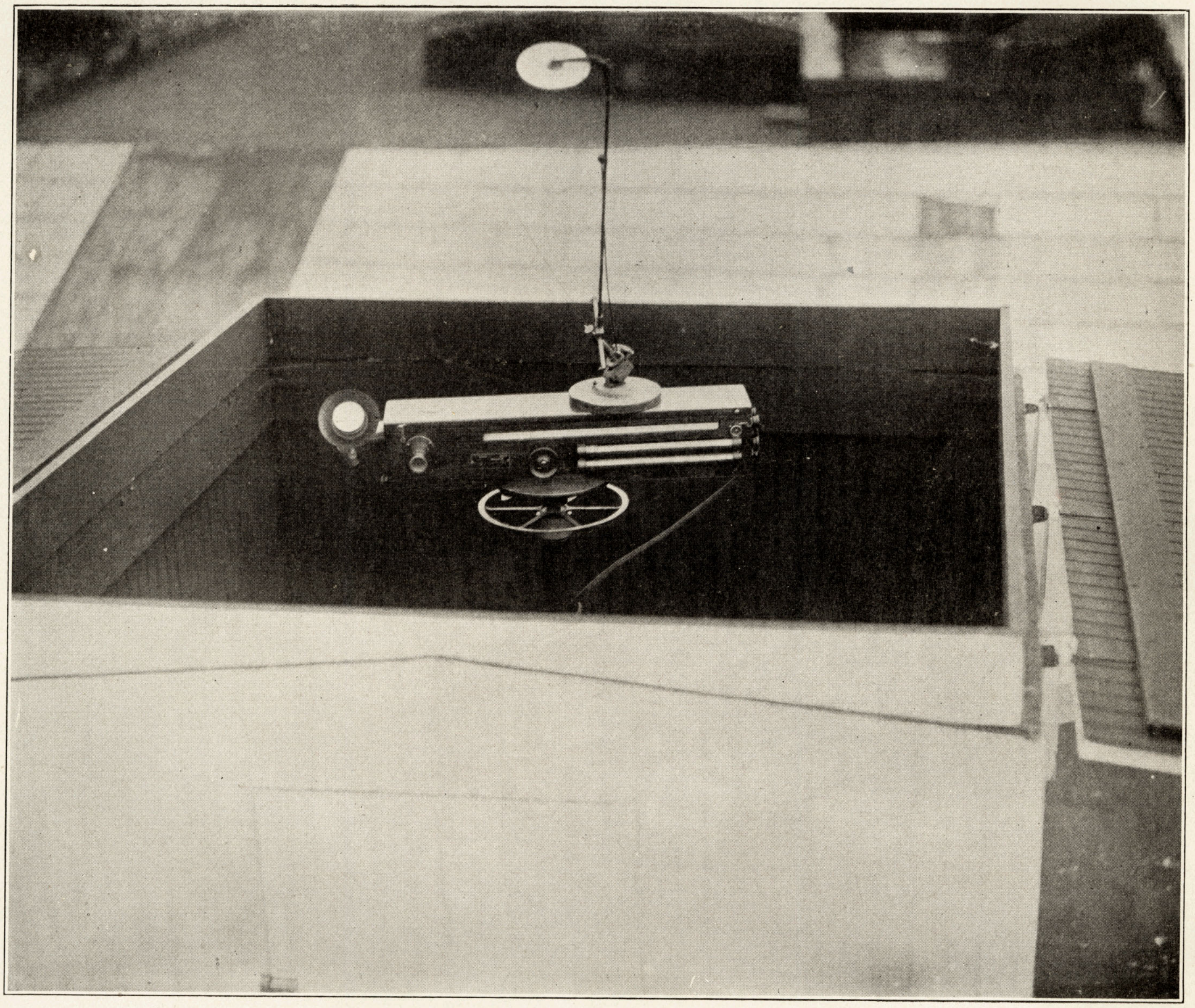
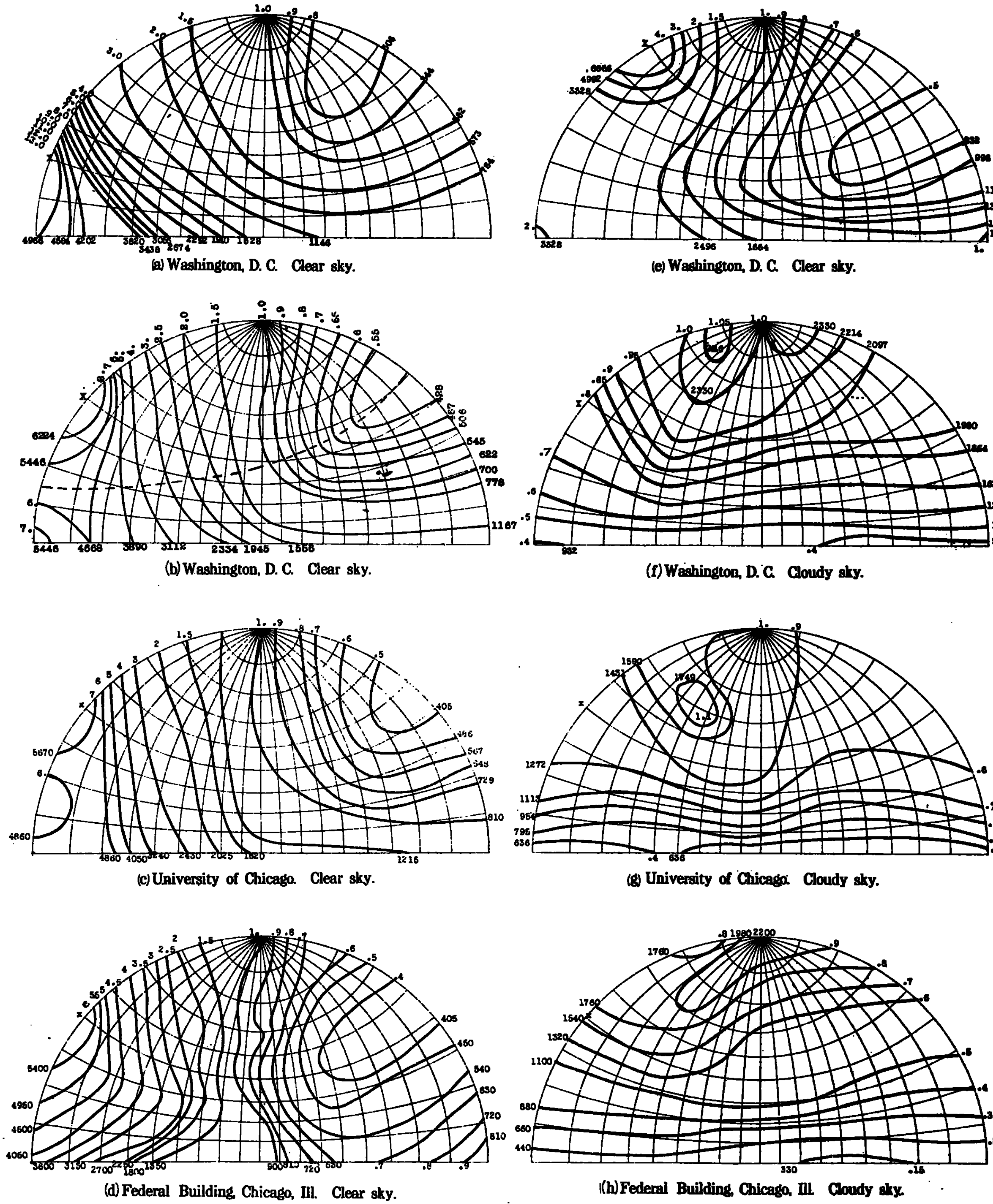


Fig. 1.—Photometer and shelter.



(a) Washington, D. C. Clear sky.

(e) Washington, D. C. Clear sky.

(b) Washington, D. C. Clear sky.

(f) Washington, D. C. Cloudy sky.

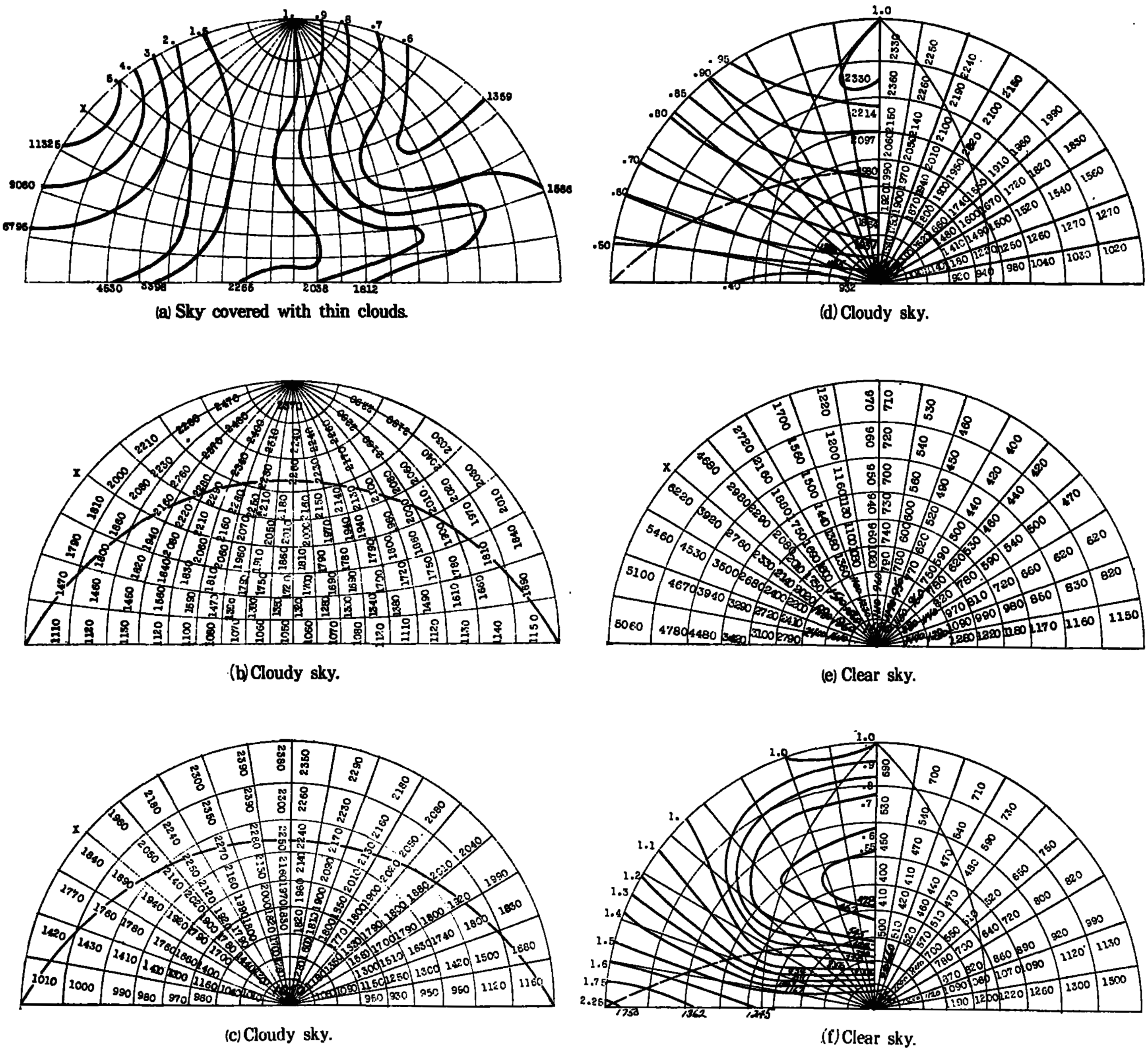
(c) University of Chicago. Clear sky.

(g) University of Chicago. Cloudy sky.

(d) Federal Building, Chicago, Ill. Clear sky.

(h) Federal Building, Chicago, Ill. Cloudy sky.

FIG. 2.—Sky brightness in millilamberts. Sun's position indicated by X. Stereographic projection.



(a) Sky covered with thin clouds.

(d) Cloudy sky.

(b) Cloudy sky.

(e) Clear sky.

(c) Cloudy sky.

(f) Clear sky.

FIG. 3.—Sky brightness at Washington, D. C., in millilamberts. Solar altitude 40°, and position indicated by X in (a), (b), (c), and (e). Stereographic projection.

white clouds reflect about 78 per cent of the light that they receive, and that the cloud surfaces may be from five to ten times as bright as adjacent patches of blue sky.

TABLE 1.—*Means of daylight illumination measurements.*

CLOUDLESS SKY.

Place.	Solar altitude.	Solar illumination.		Skylight illumination.					
		Normal incidence.	On horizontal surface.	On horizontal surface.	On vertical surface. Azimuth from sun.				
					0°	45°	90°	135°	180°
	°	*F. C.*	*F. C.*	*F. C.*	*F.*	*F. C.*	*F. C.*	*F. C.*	*F. C.*
Chicago, U	6	1,220	205	339					
Washington	24	4,870	2,020	996					
Chicago, U	22	5,840	1,850	912					
Chicago, F	23	3,880	1,260	939					
Washington	42	7,920	5,560	1,340	1,580	1,320	849	[1] 575	[1] 534
Chicago, U	41	6,410	4,060	1,400					
Chicago, F	41	6,100	3,440	1,300					
Washington	60	8,970	6,450	1,740	1,440	1,280	960	[1] 760	[1] 580
Chicago, U	60	7,840	7,130	2,000					
Chicago, F	58	8,380	7,590	1,380					
PARTLY CLOUDY SKY.									
Chicago, U	20	2,260	508	1,180					
Chicago, F	20	....	1,080	1,050					
Washington	40	4,520	3,150	3,040	2,800	2,470	1,560	[1] 1,020	[1] 762
Chicago, U	40	4,660	2,800	1,530					
Chicago, F	40	5,320	2,690	2,160					
Washington	60	4,550	3,090	3,980	2,310	2,060	1,600	[1] 1,780	[1] 1,230
Chicago, U	60	6,910	5,850	3,210					
Chicago, F	60	5,690	2,660	3,140					
Washington	70	4,280	3,720	4,360	2,180	1,920	1,650	[1] 1,540	[1] 1,520
CLOUDY SKY.									
Chicago, U	20	....	....	840					
Chicago, F	20	....	....	566					
Washington	40	....	....	1,990	925	926	849	792	782
Chicago, U	41	....	....	1,736					
Chicago, F	40	....	....	1,315					
Washington	60	....	....	2,150	881	941	977	932	929
Chicago, U	60	....	....	1,871					
Chicago, F	60	....	....	792					
Washington	70	....	....	3,450	1,290	1,250	1,210	1,220	1,310

[1] Comparison with Table 5 indicates that these values are too high, on account of the reflection of direct solar illumination from the blackened interior walls of the photometer shelter.

NOTE.—Chicago, U.=University of Chicago; Chicago, F.=Federal Building, Chicago.

SUMMARY OF DAYLIGHT-ILLUMINATION MEASUREMENTS.

In Table 1 are given the means of daylight illumination measurements made at Washington and Chicago. The only important differences to be noted are between the solar illumination measurements at Washington and at the Federal Building, Chicago. With the sun not more than 40° above the horizon the latter average less than 80 per cent of the former. The Washington measurements are also a few per cent higher than those obtained at Mount Weather, Va., in 1914.[7]

There is a marked increase in direct solar illumination with increase in solar altitude, especially on a horizontal surface, and also an increase in sky illumination on a horizontal surface. The increase in the illumination on vertical surfaces is not so marked, and the difference between the illumination on a surface facing 0° and 180°, respectively, in azimuth from the sun, grows less with increased solar altitude.

Direct solar-illumination measurements show extreme departures from the mean value of about ±30 per cent with solar altitude 40°, ±20 per cent with solar altitude 60°, and ±12 per cent with solar altitude 70°. Sky illumination on a horizontal surface, with few or no clouds present shows variations from the mean of about ±40 per cent regardless of solar altitude. In the case of both solar and sky illumination, however, the extreme plus departures are greater than the extreme minus departures.

The illumination on vertical surfaces with the sky partly covered with clouds shows variations of about ±60 per cent on each side of the mean. Or, roughly, the maximum sky illumination measured on a vertical surface has been about four times the minimum illumination measured on the same surface. Illumination from a cloudy sky shows about the same order of variation.

COMPUTATION OF DAYLIGHT ILLUMINATION FROM SKY-BRIGHTNESS MEASUREMENTS.

Moore and Abbot[8] have shown that the illumination on a horizontal surface may be computed from sky brightness measurements as follows:

Suppose the hemispherical sky surface of radius r to be divided into elementary horizontal zones, and let the angular altitude of these zones above the horizon $=\theta$. Then the radius of any zone $=r\cos\theta$, and the circumference $=2\pi r\cos\theta$. Let the width of the zone $=r\,d\,\theta$; its area $=2\pi r^2\cos\theta d\,\theta$. Let the sky brightness everywhere = one unit, and the horizontal light intensity due to the brightness of an elementary zone $=dI$

$$\text{Then } I=\int_{\theta=0}^{\theta=\frac{\pi}{2}} 2\pi r^2\cos\theta\sin\theta d\,\theta$$
$$=\pi\, r^2\sin^2\theta \qquad (1)$$

Taking zones 10° in width as in chart 10, and solving equation (1) for the limiting values assigned to θ, we obtain the relative values of I given in Table 2, after dividing out the common factor πr^2.

TABLE 2.—*Relative values of I for different values of θ.*

$\theta=$	0°–10°	10°–20°	20°–30°	30°–40°	40°–50°	50°–60°	60°–70°	70°–80°	80°–90°
$I=$	0.030	0.087	0.133	0.163	0.174	0.163	0.133	0.087	0.030

These relative values are to be multiplied by the average brightness of the respective zones, which is best obtained by first estimating the average brightness of spherical polygons measuring 10° on a side, as shown on figure 3, (b), which is based on the equal brightness lines of figure 2 (f). The average brightness of each zone is then easily computed from the brightness of the polygons it contains.

A similar method may be followed in computing the illumination intensity from the sky brightness on any plane surface, as, for example, upon a vertical surface, provided the zones of equal width are drawn concentric about a line normal to that surface. Figure 3, (c) and (d), are examples of such concentric zones, and are arranged for the computation of the illumination upon vertical surfaces facing 90° and 180° in azimuth, respectively, from the sun. These two figures are also constructed from the data given on figure 2 (f).

As an illustration of the computation we have taken the data given in Table 3, which is derived from readings on three cloudy days in May, 1921, with the sun 40° above the horizon. Table 4 gives the different steps of the computation, and the resulting illumination in foot-candles.

[7] MONTHLY WEATHER REVIEW, December, 1914, 42 : 652.

[8] Moore, A. F., and Abbot, H. L. The Brightness of the Sky. *Smithsonian Misc. Collection*, vol. 71, No. 4, p. 14.

TABLE 3.—*Sky brightness in terms of zenith brightness; cloudy sky.*

[Mean of May 25, 26, and 27. Solar altitude=40°.]

Azimuth from sun.	Altitude of point observed.							Zenith brightness.	Measured illumination, vertical surface.
	2°.	15°.	30°.	45°.	60°.	75°.	90°.		
°								*Ml.*	*F. C.*
0	0.476	0.715	1.069	1.174	1.166	1.173	1.00	2,098	978
45	0.439	0.624	0.835	0.977	0.980	0.966	1.00	2,290	1,026
90	0.320	0.433	0.611	0.722	0.936	0.929	1.00	2,564	799
135	0.342	0.477	0.663	0.708	0.941	1.102	1.00	2,764	725
180	0.325	0.475	0.670	0.641	0.806	0.826	1.00	2,932	693
Mean								2,530	
Horizontal surface illumination									1,718

TABLE 4.—*Illumination computed from sky brightness.*

On vertical surface 90° from sun.					On horizontal surface.		
					Sky brightness.		
(1) Sky zone (degrees from normal).	(2) (From Table 2.) Relative value.	(3) (From chart.) Sky brightness.	(4)=(2)×(3). Vertical component (3).	(5)=(4)×0.929. Illumination.	(6) (From chart.)	(7)=(2)×(6).	(8)=(7)×0.929. Illumination.
°		*Ml.*	*Ml.*	*F. C.*	*Ml.*	*Ml.*	*F. C.*
0-10	0.030	980	29.40		1,048	31.44	
10-20	0.087	1,075	93.52		1,352	117.62	
20-30	0.133	1,232	163.86		1,693	225.17	
30-40	0.163	1,439	234.56		1,957	318.99	
40-50	0.174	1,581	275.09		2,057	357.92	
50-60	0.163	1,787	291.28		2,269	369.85	
60-70	0.133	1,908	253.76		2,404	319.73	
70-80	0.087	2,018	175.44		2,498	217.48	
80-90	0.030	2,091	62.73		2,530	75.90	
Total			1,579.64			2,034.10	1,890
½ total			789.8	734			

On vertical surface 180° from sun.					Shading by buildings on opposite side of street. h=w.		
					Sky obscured.		
					(6) (From Fig.3(d).)	(7)=(4)×(6).	(8)=(7)×0.929.
°		*Ml.*	*Ml.*	*F. C.*	*Per cent.*	*Ml.*	*F. C.*
0-10	0.030	949	28.47		100.0	28.47	
10-20	0.087	1,068	92.92		100.0	92.92	
20-30	0.133	1,230	163.59		100.0	163.59	
30-40	0.163	1,357	221.19		100.0	221.19	
40-50	0.174	1,460	254.04		81.9	208.00	
50-60	0.163	1,537	250.53		38.6	96.90	
60-70	0.133	1,672	222.38		19.5	43.30	
70-80	0.087	1,832	159.38		9.5	15.10	
80-90	0.030	1,828	54.84		3.2	1.75	
Total			1,447.34			871.22	
½ total			723.7	672		435.61	405

It will be noted that the measured illumination on vertical surfaces is a little greater than the computed, perhaps because of the reflection of some light from the blackened walls of the shelter. On the other hand, the computed illumination on a horizontal surface is 10 per cent greater than the measured, but this discrepancy is not great when we consider the variation in sky brightness indicated by the zenith brightness measurements.

The results of a computation of the illumination upon vertical surfaces facing 180° in azimuth from the sun, from the sky brightness measurements made at the American University, District of Columbia, and the Federal Building, Chicago, are given in Table 5. The excess in the measured illumination on a vertical surface facing 180° from the sun, with the sky clear, as given in Table 1, over the computed values for Washington given in Table 5, is fully explained by the reflection of direct sunlight from the blackened interior walls of the photometer shelter. With a cloudy sky it will be noted that the difference is small.

TABLE 5.—*Illumination on a vertical surface facing opposite the sun computed from sky brightness.*

Place.	Character of sky.	Solar altitude.	Illumination.		
			F. C.	Ratio $\frac{\text{Chicago}}{\text{Washington}}$	
				Observed.	Corrected for difference in zenith brightness.
		°			
Washington	Clear	20	298		
Chicago	...do	20	207	0.694	
Washington	...do	40	363		
Chicago	...do	40	253	.697	
Washington	...do	60	498		
Chicago	...do	60	390	.782	
Washington	Cloudy	40	737		
Chicago	...do	40	410	.556	0.599
Washington	...do	60	957		
Chicago	...do	60	349	.365	.576

Since August 1 was the only cloudy day on which sky brightness measurements were made at the Federal Building, Chicago, the zenith brightness of this day can not be considered the average for cloudy skies at Chicago. The ratio of the mean zenith brightness with a cloudy sky at Washington to the zenith brightness measured at Chicago on August 1 is 1.059 for solar altitude 40° and 1.578 for solar altitude 60°. Multiplying the observed ratios for a cloudy sky in Table 5 by the ratios just given, respectively, we obtain 0.599 and 0.576, which probably better represent the relative illumination intensities at the two places than the observed ratios.

The data of Table 5 lead to the following conclusion: The daylight illumination on a vertical surface facing opposite the sun, and with an unobstructed exposure to the sky, in the Loop district of Chicago under summer conditions as regards smoke, averages only about two-thirds as intense as the illumination on a similarly exposed surface at Washington under similar sky conditions with respect to clouds, except when the sun is more than 40° above the horizon and the sky is clear.

THE SHADING EFFECT OF BUILDINGS AND OTHER OBJECTS.

For computing the shading effect of buildings on the opposite side of a street we have the following equation:

Let w = the width of the clear street space, h = the height to which opposite buildings extend above the center of a window that is under consideration, α = the angle between a line normal to the window surface and a horizontal line drawn to a point p on the row of buildings, and θ the angular height of the building above the point p, as seen from the center of the window. Then

$$\text{Tan}\ \theta = h/w\sqrt{\frac{1}{1+\tan^2\alpha}} \qquad (2)$$

Let $h=2w$, w, and $\frac{1}{2}w$, respectively, and let the row of buildings be of infinite length. We obtain the following relations between α and θ.

	α=	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°
h/w=2	θ=	63.4°	63.1°	62.0°	60.0°	56.9°	52.1°	45.0°	34.4°	19.1°	0.0°
h/w=1	θ=	45.0°	44.6°	43.3°	40.9°	37.5°	32.7°	26.6°	18.9°	9.8°	0.0°
h/w=½	θ=	26.6°	26.2°	25.2°	23.4°	21.0°	17.8°	14.0°	9.7°	5.0°	0.0°

On figure 3, (b) and (c), the area below the broken line represents the sky area cut off by a row of buildings where $h=2w$; on figure 3, (d), it represents the sky area cut off by buildings where $h=w$, and on figure 3, (f), it represents the area cut off by buildings where $h=\frac{1}{2}w$.

It is to be noted that any obstruction on the horizon cuts off the portion of the sky that is most efficient for lighting vertical surfaces, such as the side windows of buildings, and especially if the sky is clear.

In Table 4 is given an example of the computation of the shading of a window by a row of buildings opposite, following brief extracts have been made with the consent of Mr. Smirnoff and Mr. R. B. Patterson, engineer for the company:

The District of Columbia has a double system of electrical supply; alternating current for the greater part of the residential section and direct current for the greater part of the business section. There is a comparatively small industrial load in the District, a condition favorable to a study of the relation between daylight and load.

It has been found that during the day in the business section a sudden increase in current consumption occurs when the daylight illumination intensity falls below 1,500-foot candles. The lower the intensity the higher the current consumption, but fluctuations in intensity above 1,800-foot candles have only a negligible effect.

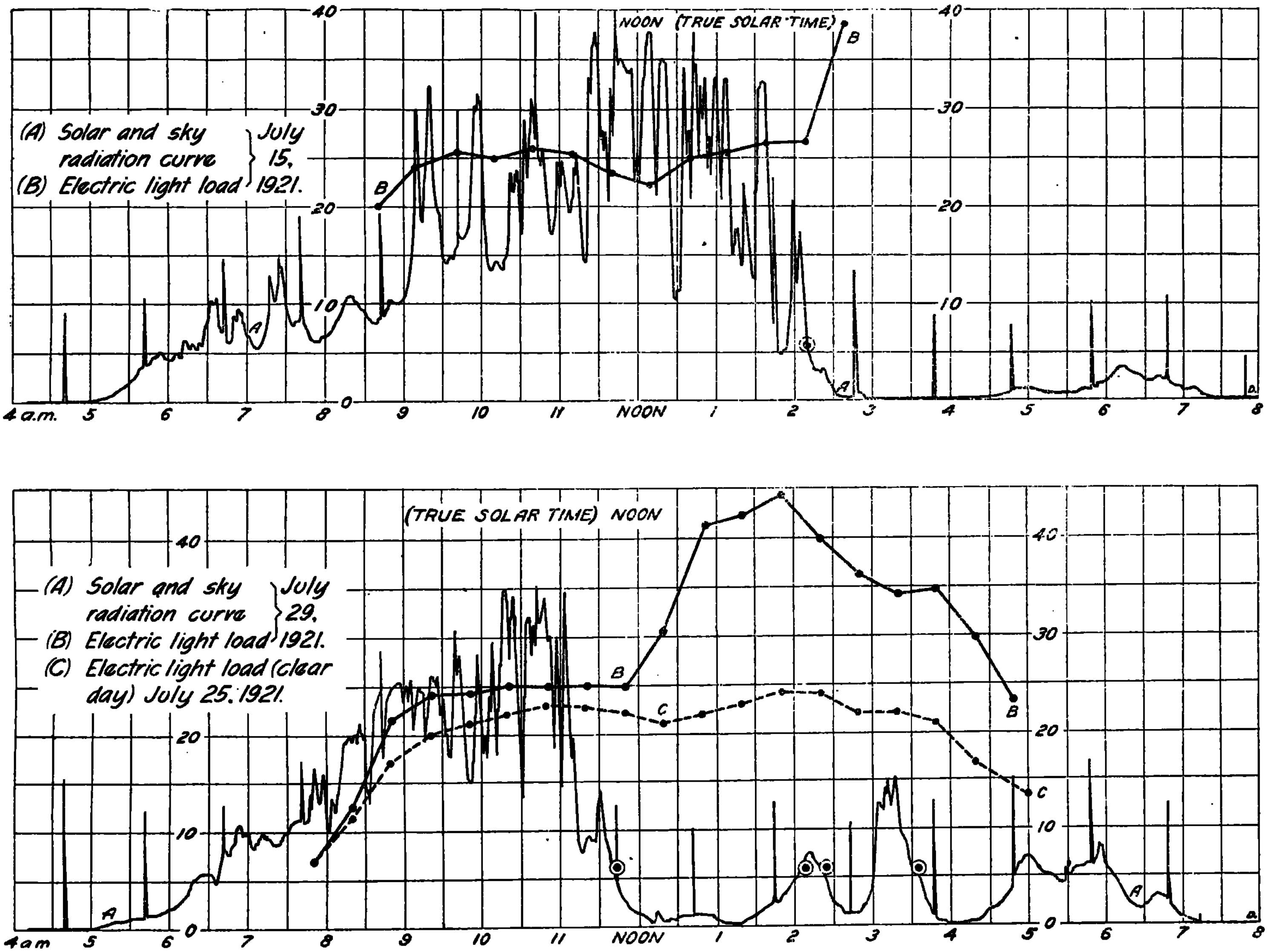


FIG. 4.—Comparison of solar and sky radiation intensity with electric light load.

with $h=w$, using the data contained in Fig. 3 (d). In this case the proportion of skylight cut off equals 405/672, or about 60 per cent.

It is possible to extend these computations so as to determine the illumination resulting from exposure to any known area of the sky, which would, of course, vary with the character of the sky and time of day.

The reflection of light from ground surfaces and from the walls of buildings and other objects is an important subject that will receive future consideration.

The utility of measurements and computations such as the foregoing is clearly shown by recent unpublished studies by Mr. A. Smirnoff, statistician of the Potomac Electric Power Co., Washington, D. C., from which the

There are two general causes of decrease in daylight illumination: (1) Decreased solar altitude, and (2) increased cloudiness.

With reference to (1) the time of the occurrence of an intensity of 1,500 foot-candles with a clear sky at different latitudes has already been computed.[9] While we expect to increase the accuracy of these computed values, Mr. Smirnoff has already pointed out their present utility.

With reference to (2) the greatest interest attaches to the rapid diminution in daylight intensity in summer in connection with severe thunderstorms. On July 15 of

[9] Kimball, Herbert H. Variations in the total and luminous solar radiation with geographical position in the United States. Mo. WEATHER REV., November, 1919, 47; pp. 789-790, figs. 16-18.

this year in Washington shortly after 3 p. m. an unusually severe thunderstorm caused the daylight intensity to fall rapidly to something like a foot-candle, and the resulting sudden increase in load was probably one of the factors that put the Electric Power plant temporarily out of commission. The darkness lasted for about an hour. Figure 4, which was prepared by Mr. Smirnoff, enables us to compare the intensity of solar and sky radiation on this day, and also on July 29, 1921, with the electric lighting load. It will be noted that whenever the radiation intensity fell to about six units on the vertical scale of the record, or about 0.25 gram-calories per minute per square centimeter, =1,500 foot-candles of illumination, the electric lighting load always increased, on account of more lights being used.

Acknowledgment is made of our indebtedness to Prof. Henry J. Cox, in charge of the local office of the Weather Bureau at Chicago, Ill., and to the members of his office force, for assistance given in connection with the observational work at Chicago. Especial mention should be made of Mr. Paul E. Johnson, who made many of the readings at the University of Chicago, and Mr. William L. Maloney, who made a part of the readings on the dome of the Federal Building. Observational work at the latter point was carried on under adverse conditions; without the hearty cooperation of Prof. Cox and his assistants, it would have been impossible.

SUMMARY.

From measurements of sky brightness that have been made at Washington and Chicago, charts have been prepared showing the brightness of the sky under different conditions of cloudiness and with the sun at different altitudes.

On these charts the sky has been divided into 10-degree zones concentric about the zenith, or about selected points on the horizon, and the brightness of these zones determined for typical sky conditions.

It is shown that with these data it becomes possible to compute the illumination resulting from the sky brightness on a horizontal surface and on vertical surfaces facing the selected points on the horizon.

A method is also given for taking account of the shading effect of buildings and other objects. This makes it possible to compute for average sky conditions of the various types the illumination that results from exposure to any given portion of the sky at any hour of the day or season of the year. The standard deviation and the extreme deviations from these mean values may also be given.

While each case becomes a separate and distinct problem, it is believed that for the more important industrial centers tables may be prepared covering a majority of cases that will arise, and perhaps differentiating between good and bad illumination.

UNIVERSITY COOPERATION IN SKY BRIGHTNESS MEASUREMENTS.

In the discussion of the report of the Committee on Sky Brightness of the Illuminating Engineering Society at the recent convention in Rochester, N. Y., it was suggested that the universities might cooperate in this work by assigning it as the subject of a thesis for an advanced student. The Weather Bureau would welcome such cooperation, and suggests that universities wishing to undertake this work correspond with Dr. H. H. Kimball, Weather Bureau, Washington, D. C., Chairman of the Committee on Sky Brightness, I. E. S.

It seems desirable that work along this line if undertaken by different individuals or institutions should be coordinated, so that measurements made in different localities may be comparable, and also to avoid unnecessary duplication.—*H. H. K.*

COMPARISON OF DIFFUSE AND DIRECT SOLAR RADIATION.[1]

551.52(048)

By J. VALLOT.

[Reprinted from *Science Abstracts*, Aug. 31, 1921, p. 548, § 1384.]

Employing Arago and Michelson actinometers, the latter for direct solar radiation, determinations were made at Nice, hourly from 8h. to 16h. on 30 clear days distributed throughout the year, of I_s, the intensity of direct solar radiation, I_t, the total radiation, and $I_{t'}$, the total radiation diminished by I_R; where I_R is the amount reflected from the earth's surface. From these are deduced $I_d = I_t - I_s$, $I_r = I_t - I_{t'}$, and $I_c = I_{t'} - I_s = I_d - I_r$. The diurnal and seasonal variation of all these quantities and of the ratios I_t/I_s, I_d/I_s, I_c/I_s, and I_r/I_t are exhibited in tabular form. The last ratio is found to increase slightly with the height of the sun, but never to reach the value 0.1. The chief result is, however, the considerable magnitude of the ratios I_d/I_s and I_c/I_s. On clear days the former is on an average as large as 0.33, and the latter 0.23. On cloudy days these ratios would of course be greater.—*M. A. G.*

[1] *Comptes Rendus*, May 9, 1921, 172: 1164–1167.

EQUIVALENT RADIATIVE TEMPERATURE OF THE NIGHT SKY.[1]

551.52:551.524 (048)

By W. H. DINES.

[Reprinted from *Science Abstracts*, 1921, 24: 216a.]

Observations taken intermittently from September 1919 to February 1920 have given equivalent radiative temperatures of the zenith sky ranging from 180° to 280° abs., the lower values being confined to winter. Some later observations in June gave values about 264° abs. on clear nights. The seasonal range is certainly much greater than that of the actual air temperature, which is about 10° C. On heavily clouded nights the sky temperature differs little from the surface air temperature. Wind appears to make no difference to the radiation. It is estimated that on clear nights the average rate of net radiation from the earth (for the whole hemisphere) is about 150 gm. cals. per day, though the rate may reach 250 gm. cals. per day.

As regards radiation at various zenith distances, the approximate relative values of the net radiation, 100 denoting the net radiation to the zenith, found for clear nights in the last fortnight of May, were:

Altitude	90°	75°	60°	45°	30°	15°	0°
Radiation	100	99	96	89	73	43	0

—*M. A. G.*

[1] *Jour. Roy. Met'l Soc.*, London, Oct., 1920, 46: 406.